



Overview of an Advanced Hypersonic Structural Concept Test Program

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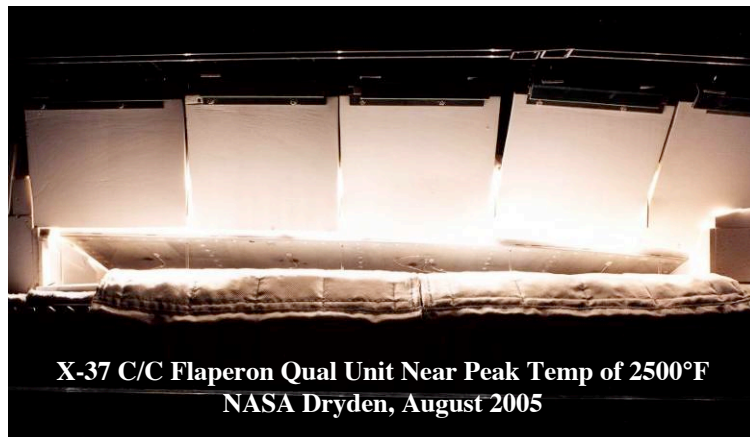


Outline

- **Hypersonics M&S Advanced Structural Concepts Development**
 - C/SiC Ruddervator Subcomponent Test Article (RSTA)
 - Background
 - Task Objectives
 - Test Plan
 - Current Status
- **Hypersonics M&S Experimental Methods**
 - Extreme Environment Sensors
 - Instrumentation Needs
 - Sensors of Interest
 - Examples of ongoing efforts
- **Conclusions**



C/SiC Ruddervator Subcomponent Test Article Background



- **One of the key technology efforts during the X-37 program was the development and validation testing of hot-structure control surfaces**
 - Part of the risk mitigation effort was the parallel development of X-37 control surfaces using both carbon-carbon (C/C) and carbon-silicon carbide (C/SiC)
- **Two separate design and manufacturing teams developed subcomponent test articles**
 - C/C Flaperon subcomponent (built and tested)
 - C/C Ruddervator subcomponent (built and tested)
 - C/SiC Flaperon subcomponent (built and tested)
 - **C/SiC Ruddervator subcomponent (built but not tested)**
- **The X-37 program down selected to C/C and proceeded with the development and testing of both ruddervator and flaperon qualification units**
 - Flaperon thermally / mechanically tested at NASA Dryden
 - Ruddervator mechanically tested at Wright-Patterson, AFB

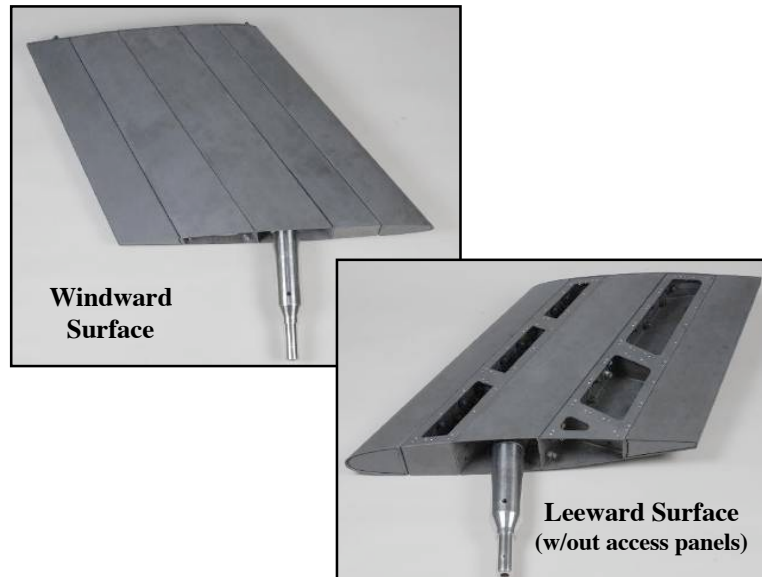


C/SiC Ruddervator Subcomponent Test Article Background (Continued)



- **NASA proposed the C/SiC RSTA as a testbed to support ARMD research objectives and worked to formulate a multi-partner program**

- Lockheed Martin (LM) is evaluating C/C and C/SiC control surface technology for hypersonic programs and expressed interest in collaborating



- **The X-37 C/SiC RSTA provides an opportunity to**

- Apply both re-entry and trans-atmospheric derived thermal / structural loads to a hot-structure
- Evaluate the thermal / structural performance of a C/SiC hot-structure control surface
- Compare the thermal / structural performance of a C/SiC and C/C hot-structure control surface
- Provide a testbed to evaluate the performance of advanced high-temperature instrumentation



C/SiC Ruddervator Subcomponent Test Article

Team Roles and Responsibilities



NASA Dryden

- Overall task management and test requirements definition
- Thermal, structural, and ground-vibration testing
- Non-destructive evaluation
- High-temperature instrumentation



NASA Langley

- Acoustic, vibration, and modal testing
- Thermal / acoustic testing



Materials Research & Design
Wayne, PA

- C/SiC RSTA designer
- Test requirements support (X-37 & LM loads)
- RSTA thermal / structural / dynamic analysis



GE Aviation
Ceramic Composite Products
Newark, DE

- C/SiC RSTA manufacturer
- RSTA modifications and assembly
- Non-destructive evaluation support



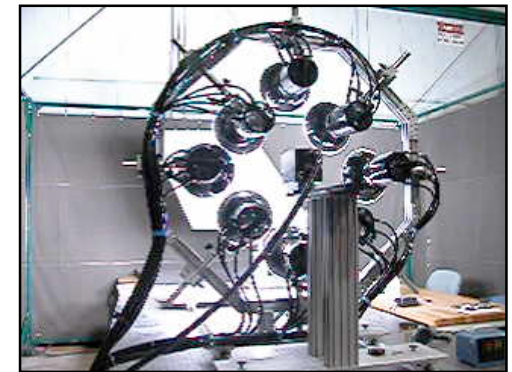
- LM derived loads definition
- Oversight of LM related testing



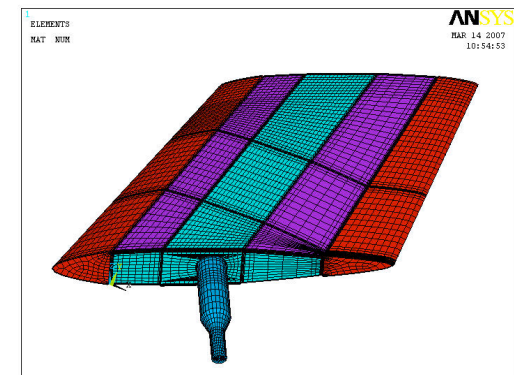
C/SiC Ruddervator Subcomponent Test Article

Test Objectives

- **Evaluate the thermal, structural, and dynamic performance of the C/SiC RSTA through the application of relevant hypersonic thermal, structural, acoustic and vibration loads**
 - Maintains and extends NASA's core knowledge in testing hypersonic structures
 - Obtain unique data through the development of test techniques
 - Application and evaluation of unique high-temperature instrumentation
 - Multi-mission simulation
 - Perform NDE throughout RSTA testing to identify defects and track potential damage propagation
- **Pre- and post-test structural analysis to support test operations and development of test database**
 - Provides an extensive database for the evaluation of design and analysis methods for hypersonic structures
 - Provides data to validate advanced analysis techniques
 - High-temperature vibration analysis
 - Using test data, non-linear material properties, and contact elements at fasteners to determine force levels at interfaces and fastener stresses (linear versus non-linear analysis comparison)



IR Pulsed Thermography NDE





C/SiC Ruddervator Subcomponent Test Article Test Plan

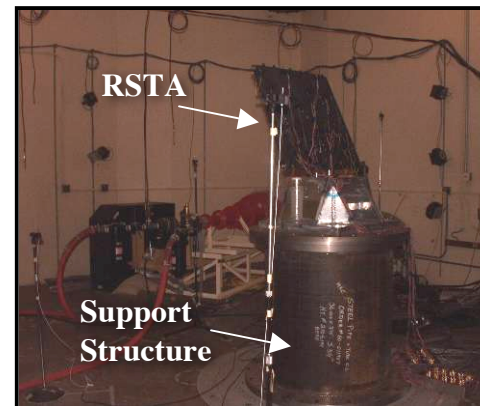
- **Evaluate RSTA performance under two different hypersonic flight conditions**
 - X-37: Re-entry conditions
 - Higher heating rates (i.e. higher surface temperatures) over shorter time periods
 - Mechanical loads over short time periods
 - Vibration / acoustic loads maximum at lift-off (i.e. low temperature conditions)
 - LM: Trans-atmospheric conditions
 - Lower heating rates (i.e. lower surface temperatures) over longer time periods
 - Mechanical loads over repeated cycles
 - Combined thermal / acoustic loads of interest
- **Developed a four-phase test program for the RSTA**
 - Phase 1: Acoustic and vibration loads to X-37 load conditions
 - Phase 2: Thermal and thermal / structural loading to X-37 and LM load conditions
 - Phase 3: Room-temperature mechanical loading to X-37 and LM load conditions
 - Phase 4: Vibration and thermal / acoustic testing to LM load conditions



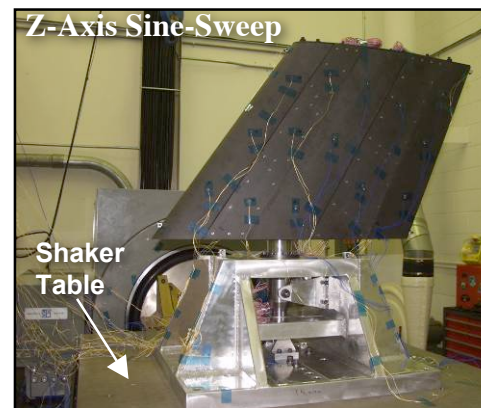
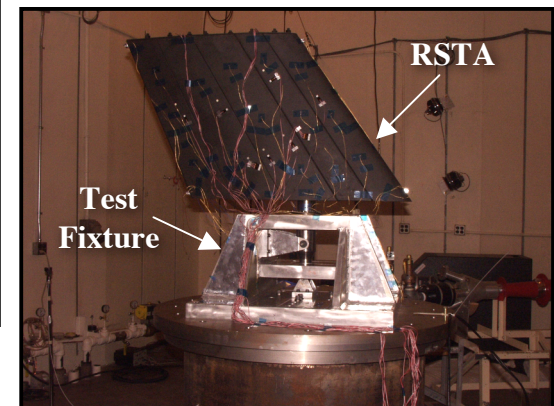
C/SiC Ruddervator Subcomponent Test Article

Phase 1 Tests (NASA Langley, Completed)

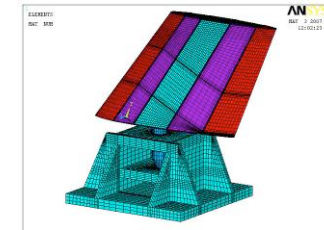
- **Objective:**
 - Evaluate RSTA dynamic performance under X-37 vibration and acoustic loads
- **Test Sequence:**
 - Modal survey
 - Free-free / fixed boundary condition
 - Pre-acoustic sine sweep
 - Acoustic testing
 - Vibration testing
 - Post-acoustic sine sweep
 - Random vibration testing
 - Post-random sine sweep
- **Data Acquired**
 - Accelerations
 - Strains
- **Database Elements**
 - Test requirements document and test plan
 - Instrumentation drawings and test data
 - Test correlation report



Acoustic Test Setup
At LaRC Reverb Chamber



Vibration Test Setup
At LaRC





C/SiC Ruddervator Subcomponent Test Article

Phase 2 Tests (NASA Dryden, In Progress)

- **Objective:**

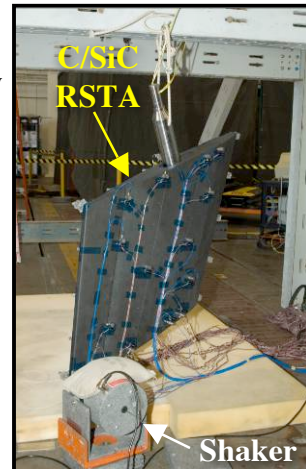
- Evaluate RSTA performance under X-37 re-entry and LM thermal / mechanical load conditions

- **Test Sequence:**

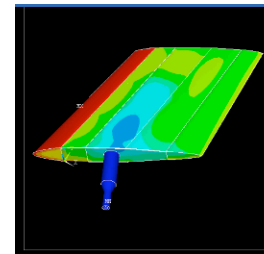
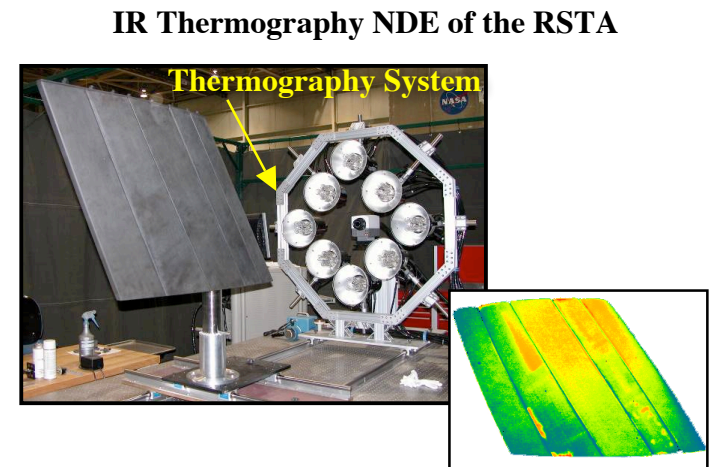
- Modal Survey (**completed**)
 - Free-free boundary condition
- Room-temperature ground vibration test (GVT)
- Elevated-temperature GVT
- X-37 thermal loading (3 cycles)
- X-37 thermal / mechanical loading (3 cycles)
- LM thermal / mechanical loading (3 cycles)
- Elevated-temperature GVT

- **Status:**

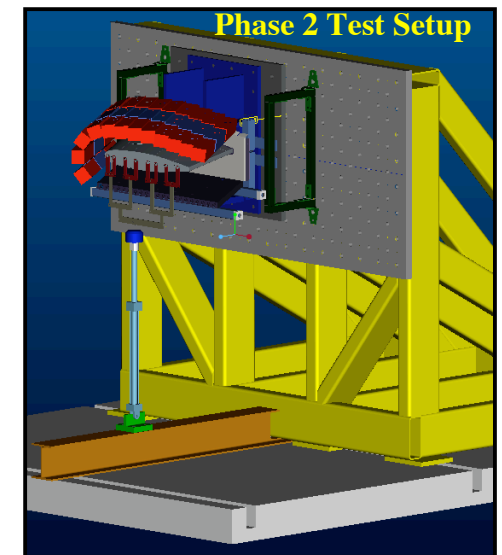
- Pre-test predictions
 - LM thermal / mechanical test conditions (**completed**)
 - X-37 thermal / mechanical test conditions (in progress)
- High-temperature sensor installations (in progress)
- Thermal test hardware design (**completed**)
- Thermal test hardware fabrication (in progress)



Free-Free Modal Survey



Transient RSTA Leeward Temps from Pre-Test Analysis of LM Trajectory

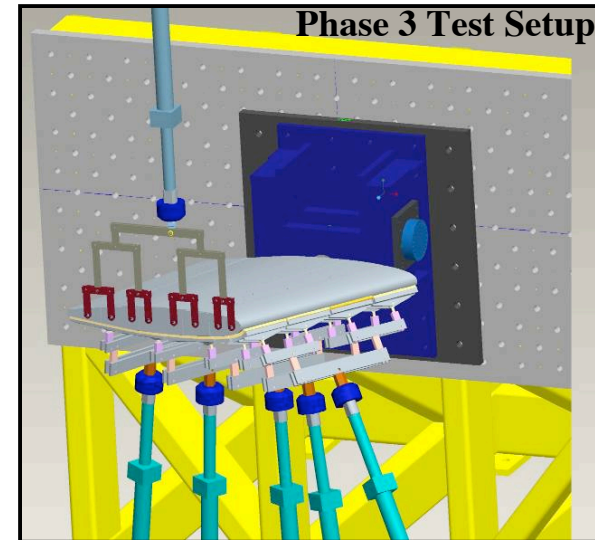




C/SiC Ruddervator Subcomponent Test Article

Phase 3 & 4 Tests

- **Phase 3 Objective: (NASA Dryden)**
 - Evaluate RSTA performance under X-37 derived 100% DLL loads
- **Test Sequence:**
 - Multi-cycle loading to 100% DLL condition
 - Reverse loading
- **Data To Be Acquired**
 - Deflections (control surface and freeplay)
 - Strains
 - Input and reaction loads
- **Phase 4 Objective: (NASA Langley, TBD)**
 - Evaluate RSTA performance under LM derived vibration and thermal / acoustic loads
- **Test Sequence:**
 - Modal survey (free-free boundary condition)
 - Pre-acoustic sine sweep
 - Thermal / Acoustic testing
 - Vibration testing
 - Post-acoustic sine sweep
 - Random vibration testing
 - Post-random sine sweep
- **Data To Be Acquired**
 - Temperatures
 - Accelerations
 - Strains



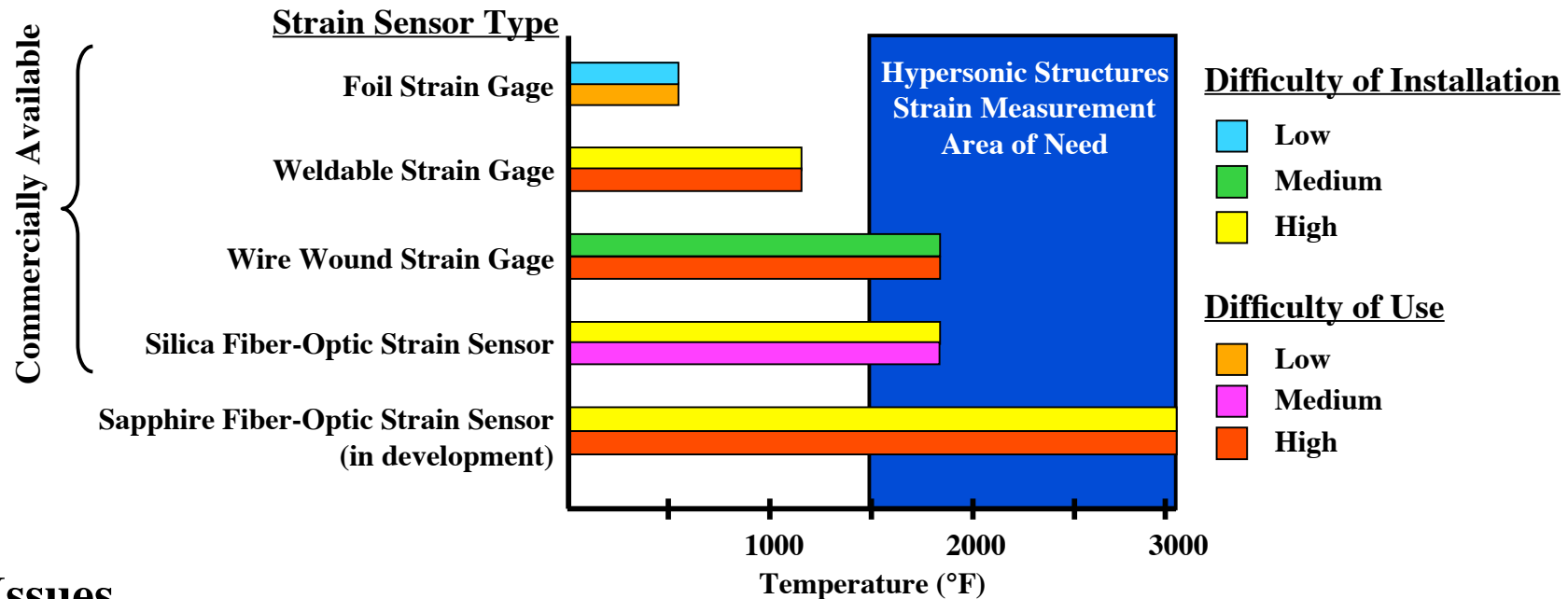
Phase 4 Test Facility





Extreme Environment Structural Sensors

High-Temperature Instrumentation Needs



• Issues

- Hypersonic structures are utilizing advanced materials that operate at temperatures that exceed current ability to measure structural performance
- Robust structural sensors that operate accurately and reliably in hypersonic environments do not exist

• Implications

- Hinders ability to validate analysis and modeling techniques
- Hinders ability to optimize structural designs



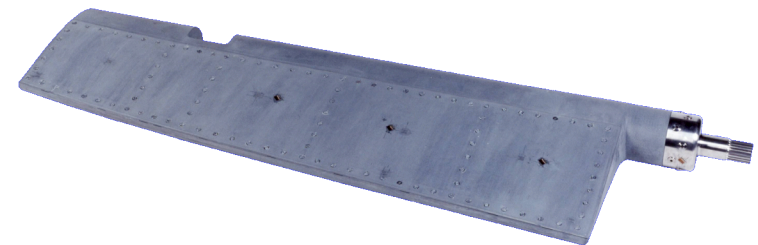
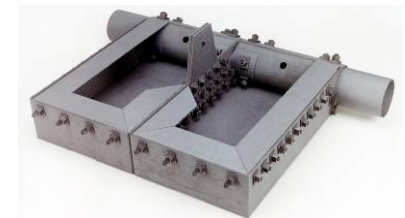
Extreme Environment Structural Sensors

Instrumentation Attachment Needs

- **Hypersonic structural test or flight articles are usually one-of-a-kind, expensive, and time consuming to manufacture**
 - Metallics
 - Metal matrix composites
 - Superalloys
 - High-temperature composites (i.e. C/C, C/SiC, SiC/SiC)

- **Issues**

- Integrating structural sensors that do not compromise structural integrity
 - Drilling holes, mechanical fastening, etc. are typically not allowed
- Developing sensor attachment methods that provide valid measurements for all environmental loading conditions without adversely affecting the substrate
 - Thermal conditions
 - Mechanical loading
 - Vibration and acoustic loads
 - Exposure to chemically reacting flows





Extreme Environment Structural Sensors

High-Temperature Structural Measurements of Interest

- **Strain**
 - Sapphire fiber-optic sensors
 - High-temperature Bragg Gratings
- **Temperature**
- **Heat Flux**
 - Calibration methods
- **Acceleration**
- **Deformation**

Sensors and Sensory Materials

**Bonding / attachment method
development throughout
structural component
operating range**

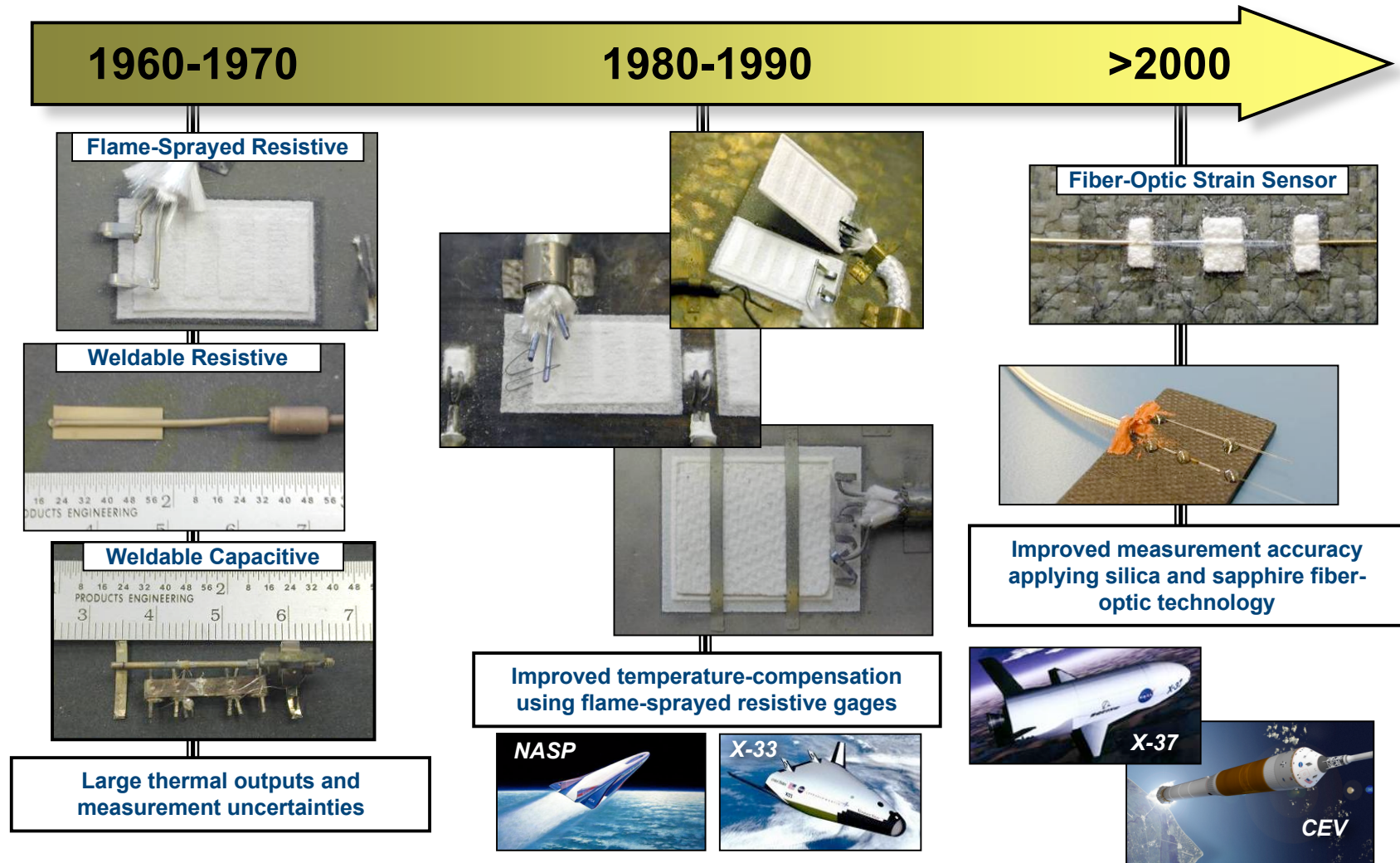
Current Efforts:

- SOA structural sensor assessment to coordinate NASA, NRA and SBIR opportunities
- Evaluate sensor / systems under laboratory, ground test, and flight test opportunities



Extreme Environment Structural Sensors

Example of Strain Sensing Technology Progression

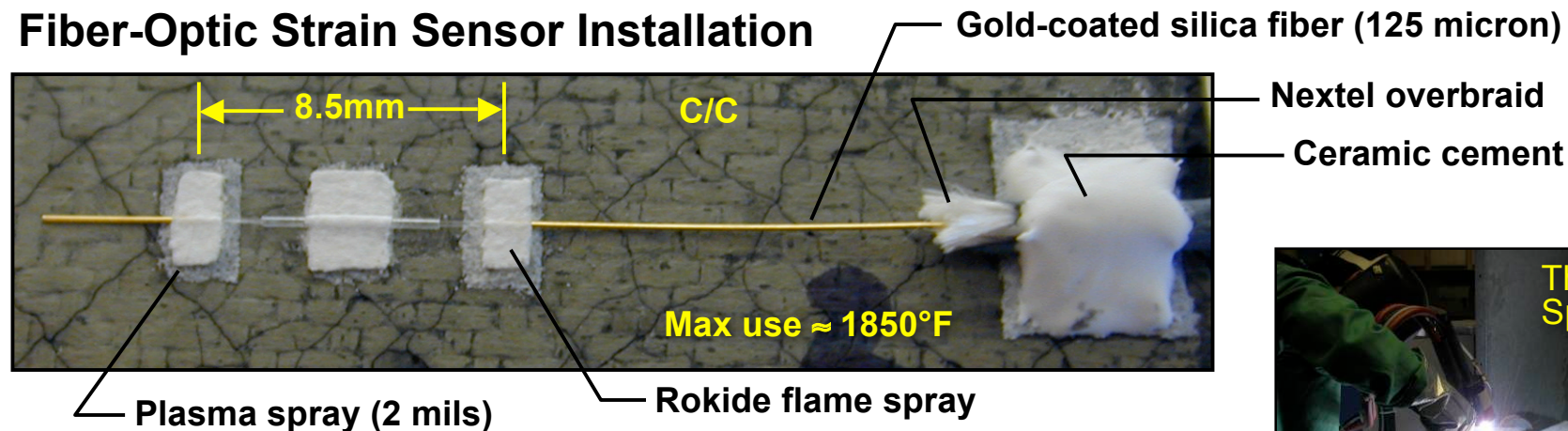




Extreme Environment Structural Sensors

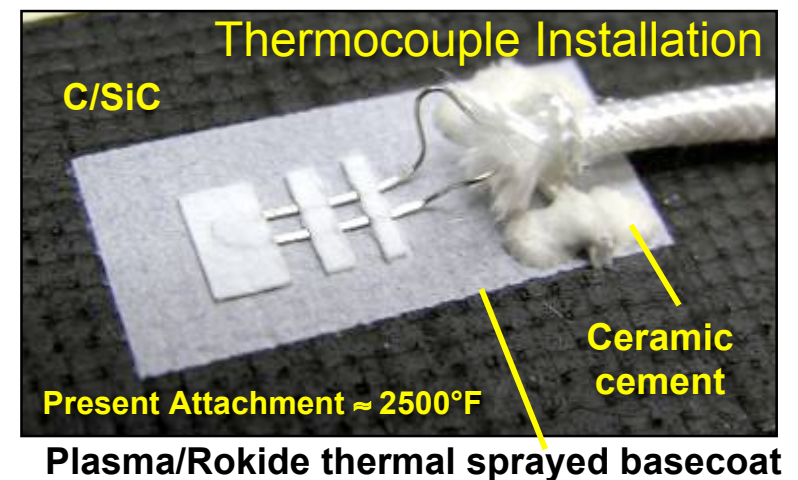
Examples of Strain and Temperature Sensors

Fiber-Optic Strain Sensor Installation



• Challenge

- Advance strain sensing technology beyond 2000°F
- Develop durable high-temperature fiber-optic sensors
- Advance temperature sensing methods
- Develop sensor attachment techniques suitable for hypersonic environments (ground and flight testing)



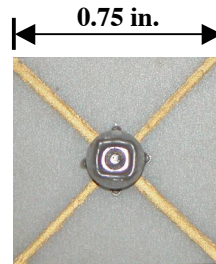


Extreme Environmental Sensors

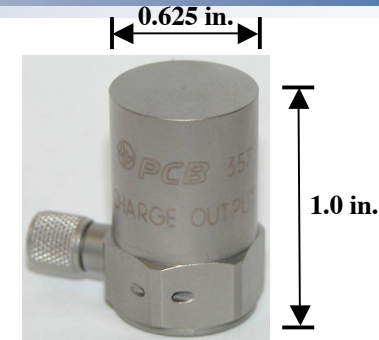
Examples of Acceleration, Heat Flux, Network Sensors

- **Accelerometers**

- COTS sensors
- NASA GRC



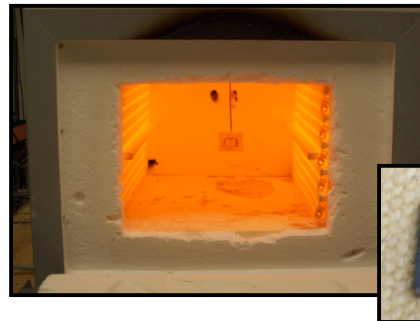
NASA GRC
High-Temperature SiC High-g sensor
(1000°F)



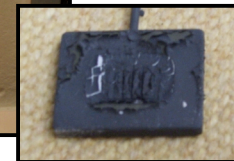
COTS
High-Temperature Accelerometer
(900°F)

- **Heat Flux Sensors**

- Low profile
- Rapid response

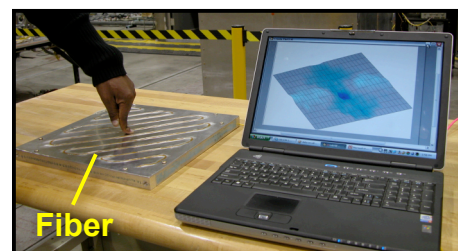


Heat Flux Array
ARMD ExCap NRA Effort
(Tao Systems and Virginia Tech)

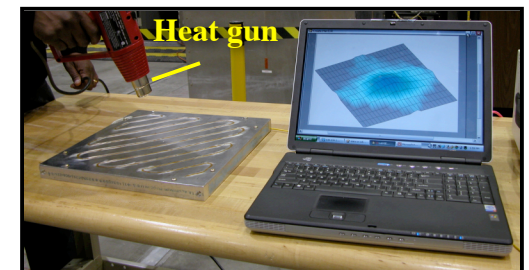


- **Distributed Bragg Grating System**

- Simultaneous measurements of strain, temperature, and deformation
- Increase operating temperature



Pressure Loading



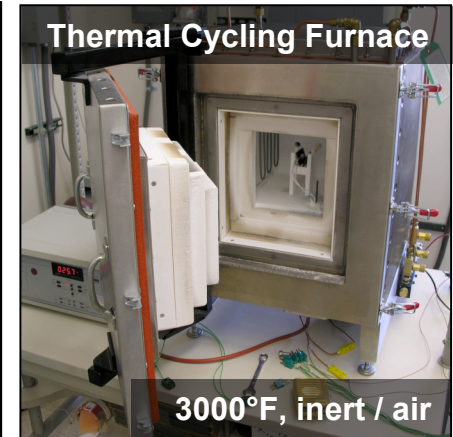
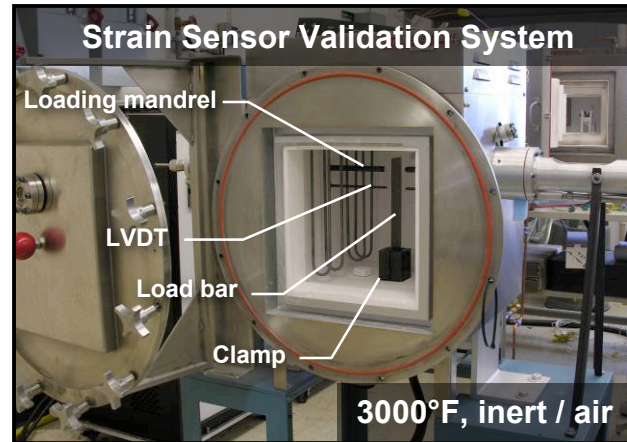
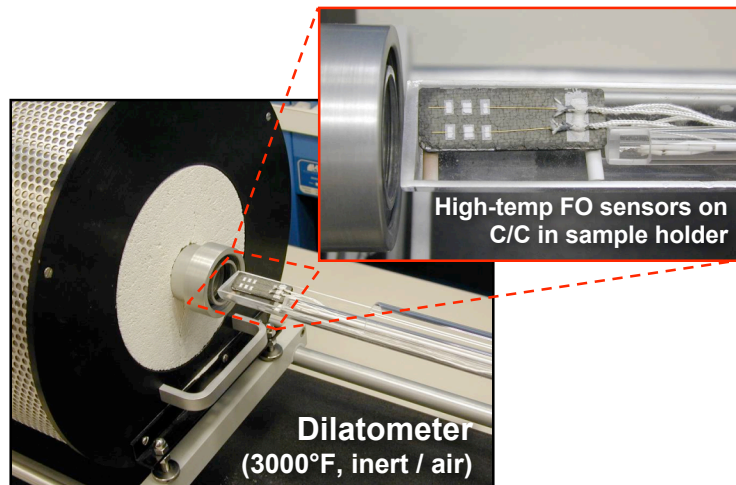
Thermal Loading



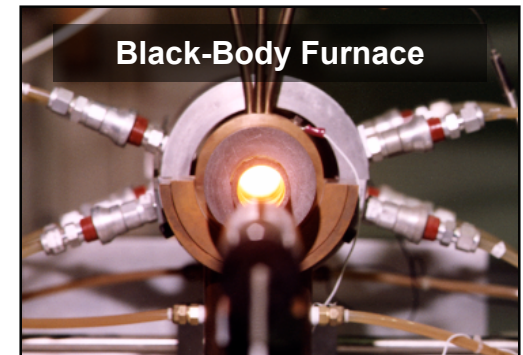
Extreme Environmental Sensors

Validation of Sensor Outputs and Attachment Methods

- **Goal: Provide valid sensor data to structural analysts**
 - Validate sensor output through characterization testing
 - Compare sensor outputs to available standards
 - Validate and assess attachment techniques



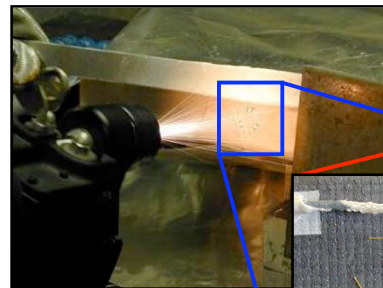
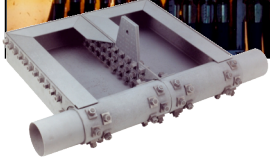
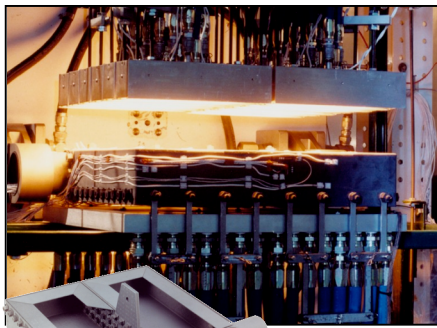
**Typical Systems for
Sensor Validation Testing**



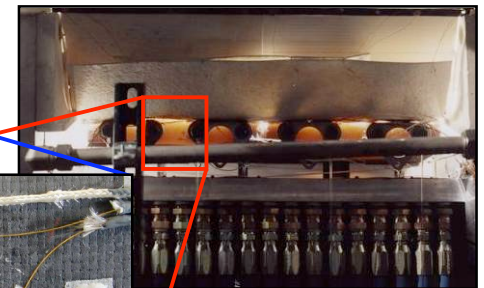
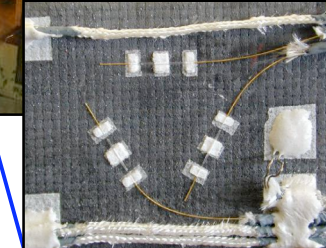


Conclusions

- **Hypersonics M&S is developing**
 - Advanced structural concepts for hypersonic vehicle applications
 - Ground test techniques to obtain data that validates structural performance and analysis techniques for design optimization
 - Sensor technology to acquire structural data subjected to hypersonic conditions for analysis validation and design optimization
 - A knowledge base for the technical community



**Thermal Spraying
Fiber-Optic
Strain Sensors**



**Fiber-Optic Strain
Sensors in Test**